2. W.N. Carey and P.E. Irick. The Pavement Serviceability Performance Concept. HRB, Bull. 250, 1960.
3. B.G. Hutchinson. Principles of Subjective Rating Scale Construction. HRB, Highway Research Record 46, 1963, pp. 60-70.
4. R.J. Weaver and R.O. Clark. Psychophysical Pavement Serviceability. Soil Mechanics Bureau, New York State Department of Transportation, Albany, May 1977.
5. J.P. Guilford. Psychometric Methods, 2nd ed. McGraw-Hill, New York, 1954.
6. W.S. Torgerson. Theory and Methods of Scaling. Wiley, New York, 1967.
7. J.B. Nick and M.S. Janoff. A Comparative Study of Psychophysical Scaling Methods for Evaluating Pavement Ride Quality. Pennsylvania Department of Transportation, Harrisburg, draft, Dec. 1981.

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High-Speed Road Monitoring System

P.G. JORDAN AND J. PORTER

A high-speed road monitoring system has been developed at the Transport and Road Research Laboratory. It consists of four laser sensors mounted on a 4.5-m-long beam that is supported by a two-wheeled trailer towed behind a small van. Measurements are made by the configuration of laser sensors under the control of a computer system located in the vehicle behind which the trailer is towed. Longitudinal profile, wheel-track rutting, and surface macrotexture are measured as the system travels over the road networks in the normal traffic stream; provision is being made for the measurement of road crossfall, gradient, and horizontal curvature. The principles of system operation in the different measurement modes are described and illustrated. Use of the measurements made by the high-speed system in studies of the effects of unevenness on the road user and in detecting structural deterioration of roads is described. Its potential for use in making surveys of the road network at a relatively low cost, locating areas of distress, and guiding the deployment of other, more specialized equipment is discussed within the context of the development of a cost-effective maintenance management system.

Large sums of money are being spent throughout the world on road maintenance. Effective use of these funds demands careful allocation of resources. In the United Kingdom the Report of the Committee on Highway Maintenance (1) recommended that highway authorities should use an objective maintenance rating system as the basis of regular road inspections. In answer to this recommendation, various computerized highway maintenance systems (2) have been developed and are in widespread use in the United Kingdom. All rely heavily on visual inspection to assess the condition of the road surface by reference to, for example, wheel-track rutting and surface cracking. These visual condition surveys are increasingly being augmented by input from machines that monitor various aspects of road condition more quickly than could a team of inspectors.

A high-speed monitoring system that measures a number of different aspects of road condition has recently been developed at the Transport and Road Research Laboratory (TRRL). Measurements are made by the system as it travels over the network in the normal traffic stream. The power of the equipment lies in its ability to cover a large distance each day, gather surface profile and alignment data that describe the condition of the network, and guide the deployment of other slower, more specialized evaluation equipment.

In this paper, the road monitoring system is described and its use in research on the effects of surface unevenness and its development as a component part of a total maintenance management system are discussed.

DESCRIPTION OF THE SYSTEM AND ITS USE

The high-speed road monitoring system (3), shown in Figure 1, is a laser-based system that accurately measures road surface characteristics. Its on-board computer facilities, shown schematically in Figure 2, provide both measurement control and an on-site data-processing capability. The system operates at speeds between 5 and 80 km/h, and its performance is not affected by variations in speed. With a driver and one operator, it can cover as much as 200 km of profile, rutting, texture, and road alignment parameters each day. Data are stored on floppy disks and can be either processed on site or transferred to a central mainframe computer for permanent storage and further processing.

Figure 1. High-speed road monitoring system.

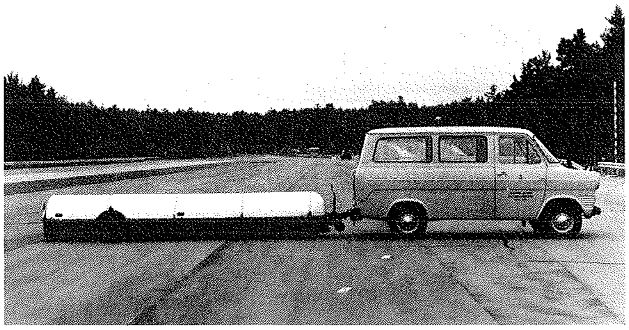
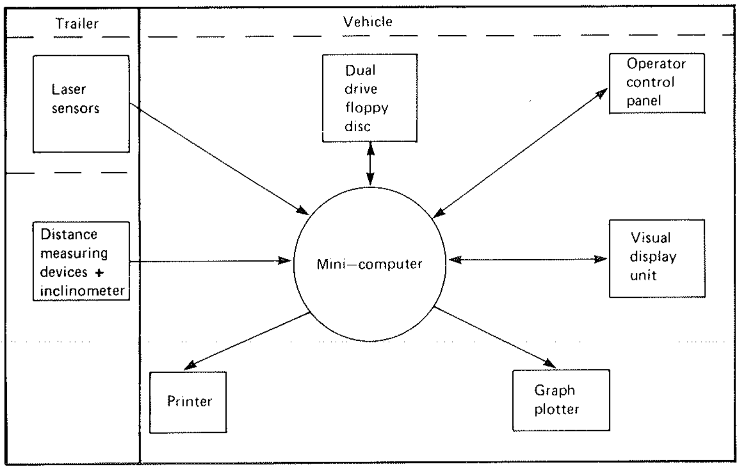


Figure 2. Computer control and analysis facilities of high-speed road monitoring system.



Laser Sensor

The essential features of the laser sensor (4) are shown in Figure 3. Laser light projection and receiving units are fixed to a rigid beam in such a way that the projection and receiving axes are orthogonal. The semiconductor laser source produces infrared light at pulse rates up to 3000/sec. The lens in the projection unit focuses the light from the laser on a 0.3-mm^2 spot on the road surface. This light is diffusely scattered by the surface; some is collected by the lens in the receiving unit and focused onto a linear array of photodiodes.

When the surface is displaced vertically in relation to the sensor, the illuminated spot moves along the axis of the projection beam. Because the projection and receiving axes are orthogonal, the image of the illuminated area formed on the diode array moves along the array and remains in focus, as shown in Figure 3. By detecting which diode in the array has maximum light intensity, the vertical distance of the sensor from the surface can be calculated.

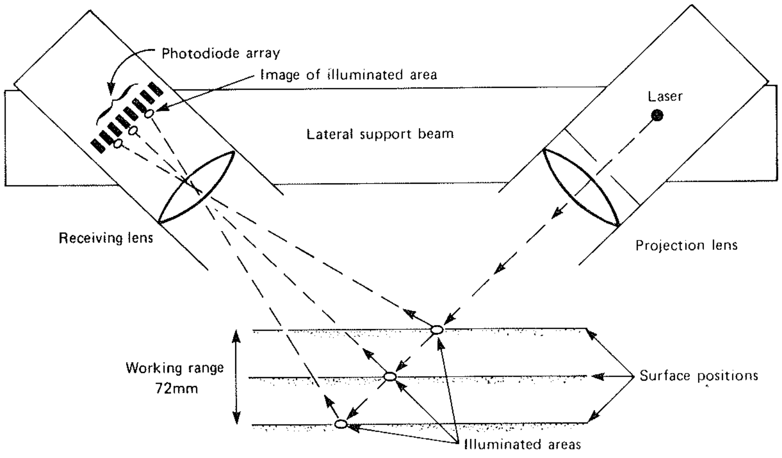
The sensor has a working range of 72 mm centered at a point 270 mm from the sensor, and resolution is +0.282 mm over the full working range.

Profile Measurement

For profile measurement the high-speed system (5) uses four laser sensors fitted to a 4.5-m-long rigid beam in the configuration shown in Figure 4. The sensor configuration provides two profile measuring systems: the symmetric (SYM) and the asymmetric (ASY). Each measures a different range of wavelengths. Profile features with wavelengths greater than 10 m are measured by using the SYM system (sensors A, C, and D in Figure 4); this computes the average profile height over a 2.14-m length (every 2.14 m) to give the long-wavelength profile of the road. The ASY system (sensors A, B, and D in Figure 4) is used to determine the profile in the 0.3- to 20-m wavelength range in terms of the average profile height over a 0.107-m length (every 0.107 m along the road). A single composite profile containing the wavelengths measured by both systems is obtained by superimposing the ASY profile on that measured by the SYM system.

The principle of operation of the profilometer is described in detail elsewhere (5). Its main features can be briefly illustrated by referring to the SYM measuring system. By moving the equipment forward a distance equal to that between the SYM sensors, the average heights h_A, h_C, and h_D of each of the sensors A, C, and D above the road surface can be computed. The averaged profile height (Y_1) of the road traversed by sensor D is referred to a datum line defined by joining the averaged heights at the center points of the lengths traversed by sensors A and C to give the averaged characteristic measurement (U_1) of the SYM system:

Figure 3. Essential features of laser sensor.



$$Y_1 = U_1 = -(h_A - 2h_C + h_D) \qquad (1)$$

An important feature of Equation 1 is that the characteristic measurement U_1 is, for all practical purposes, unaffected by changes in height or pitching of the equipment provided the surface remains within the working range of the sensors.

The equipment is now moved forward so that the positions along the surface of the averaged profile heights measured by sensors C and D are coincident with the positions of previous measurements of sensors A and C. The new averaged profile height (Y_2) is calculated by using the averaged characteristic measurements U_1 and U_2 as follows:

$$Y_2 = 2U_1 + U_2 \qquad (2)$$

In general, after n steps the averaged profile height (Y_n) is given by

$$Y_n = \sum_{i=1}^{n} (n - i + 1)\, U_i \qquad (3)$$

In the ASY system the spacing of sensors A and B in Figure 4 is 0.05 that of the SYM sensors and ASY measurements are obtained at this spacing. By using a derivation similar to that given previously, it can be shown that after m steps the profile height (Y_m) of the ASY system averaged over the ASY step length is given by

$$Y_m = [40\, Y_{(m-1)} - Y_{(m-40)} + 39\, W_m]/39 \qquad (4)$$

where W is the averaged characteristic measurement of the ASY system, which in terms of the averaged sensor measurements (h_A, h_B, and h_D) is given by

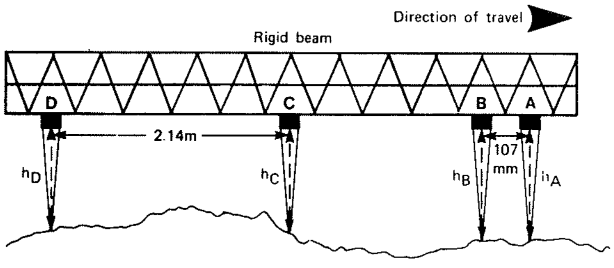
$$W = -(39\, h_A - 40\, h_B + h_D)/39 \qquad (5)$$

Equation 3 defines the long-wavelength features of the profile and Equation 4 defines the short-wavelength features. A composite profile containing both the long- and short-wave features is obtained by superimposing the ASY measurements on the SYM measurements by using a piecewise linear fitting process that is described in detail elsewhere (5). The low center of gravity of the trailer combined with the averaging used to reduce the effects of texture ensure that roll has a negligible effect on the measurements.

The performance of the TRRL high-speed system has been extensively investigated, not only by TRRL (5) but also independently by Bundesanstalt fur Strassenwessen (BAST) of West Germany (6). TRRL made detailed rod-and-level surveys at 0.1-m spacing, and BAST made continuous measurements with their profilograph along a defined line previously measured by the high-speed equipment. Bituminous and concrete surfacings containing different levels of short- and long-wave unevenness were measured. When the survey and high-speed measurements were correlated, coefficient values ranged from 0.96 to 0.99 for the surfacings examined and for profile wavelengths up to 50 m. For wavelengths up to 100 m the correlation coefficient is 0.95.

Figure 5 shows the system to have good amplitude and phase response between 0.5 and 100 m; good response is obtained up to wavelengths of several hundred meters, the upper limit being determined mainly by the level of macrotexture on the road surface (5). For wavelengths shorter than 0.5 m the amplitude response decreases because of the averaging involved in the derivation of the ASY measurements.

Figure 4. Sensor configuration on rigid beam for profile measurement.



SYM System uses Sensors ACD
ASY System uses Sensors ABD

Accuracy of measurement is affected by road surface and machine factors; the maximum tolerances expected for the measurement of amplitudes at wavelengths up to 100 m are shown in Figure 5. The ability of the system to measure long wavelengths accurately means that it can be used to examine not only the riding quality of highways and airfields but also subsidence problems. An example of subsidence measured over an 800-m length of concrete pavement is shown in Figure 6. Comparison with conventional survey measurements on this site showed agreement to be within 10 percent at the maximum amplitude.

Measurement of Wheel-Track Rutting

The method used for the measurement of wheel-track rutting (7) is shown in Figure 7. The wheels of the trailer ride in the ruts, and the laser sensor continuously measures the axle displacement from the road surface along a line centered between the wheel tracks. The difference between the axle displacement measured on a rutted surface and the data obtained on a nonrutted surface gives the rut depth averaged over both wheel tracks as shown in Figure 7.

To smooth the effect of the oscillatory motion of the trailer on its suspension, the rut measurements are averaged over a length directly proportional to the speed of the measuring system: e.g., for an operating speed of 50 km/h the length is 20 m.

Comparisons between measurements obtained by using the laser system and average rut depths derived from straightedge and wedge measurements show agreement to within 2 mm on major roads and 3 mm on minor roads (the difference arises from the greater camber on minor roads) (7).

Examples of rut depth profiles obtained by using the laser system at normal traffic speed on a motorway and on a single-carriageway principal road are compared in Figure 8 with rutting levels based on CHART system recommendations (2). The motorway is shown to have an acceptable level of rutting, but the principal road has sections that would require further investigation.

The computer facilities, shown in Figure 2, enable the storage of as much as 500 km of rut data per floppy disk. Lengths of road with critical levels of rutting can be located quickly by using the on-board analysis programs.

Measurement of Macrotexture

Macrotexture is measured (8) by using sensor C of the high-speed road monitoring system (Figure 4), which measures about 3,000 displacements/sec as it moves over the surface. The macrotexture appears in the form of small random variations in the measure-

Figure 5. Amplitude and phase-response measurement tolerances of amplitude.

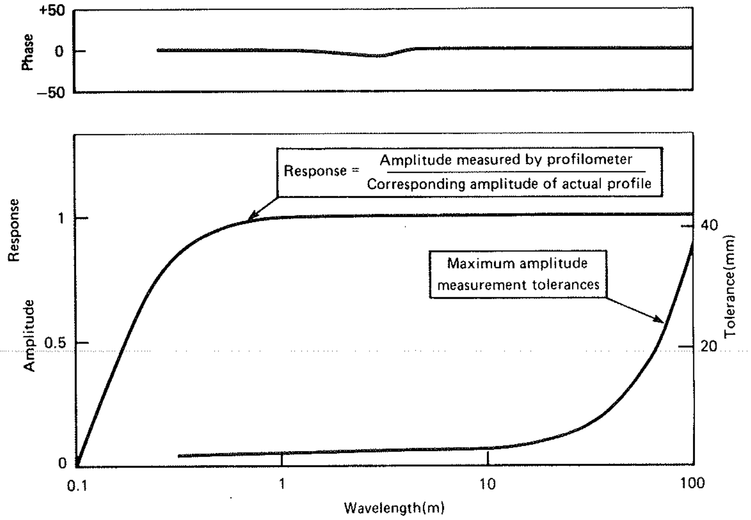
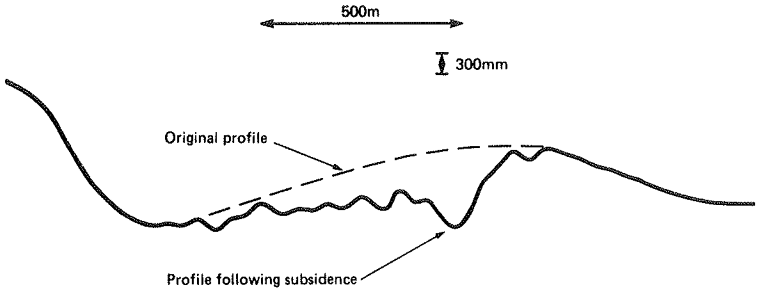


Figure 6. Measurement of subsidence profile on a continuously reinforced concrete pavement by the high-speed road monitoring system.



ments superimposed on the much larger oscillatory motion induced by the trailer suspension (see Figure 9). To obtain a measure of the macrotexture depth (8), the oscillatory motion is characterized by a piecewise parabolic curve-fitting procedure. The texture depth is then calculated in terms of the standard deviation of the residual displacements, as shown in Figure 9. The standard deviation of texture depth is calculated over short lengths of surface, usually 0.3 m; it can be presented in the form of a histogram or profile of texture depth along the road surface.

Comparison of texture measurements made by the laser sensor with those made by the more traditional sand-patch method (3) show good agreement: correlation coefficients exceed 0.9 (8). Selected sections of motorway ranging from 6 to 21 km long have been measured by using the laser system. The results have shown that the system is capable of continuous measurement of macrotexture at operating speeds up to 35 km/h (9). On grooved concrete surfaces the laser system has also been successfully applied to the measurement of groove depth and spacing (10).

Measurement of Road Cross Slope and Radius of Curvature

By using essentially the system shown in Figure 2 but with the addition of transverse and longitudinally positioned inclinometers, the capability to measure road gradient, crossfall, and radius of curvature of bends is being incorporated into the high-speed road monitoring system. The radius of curvature of bends is computed by using the difference in the distances traveled by the wheels of the trailer on rounding a bend. Road gradient and crossfall are derived from inclinometer measurements. The effects of radial acceleration on crossfall measurements are corrected by using the measured radius of curvature. Trailer roll effects are reduced to an acceptable level by averaging the crossfall measurements over a length that is related to operating speed; typically, a length of 20 m is used for a speed of 50 km/h.

Preliminary test trials have shown system measurements to be in good agreement with those obtained by using conventional survey methods.

RESEARCH ON EFFECTS OF ROAD SURFACE UNEVENNESS

To exploit fully the capabilities of the road monitoring system, more must be known about the effect of surface unevenness on (a) the comfort and safety of the road user, (b) vehicle operating costs, (c) damage to the road structure, and (d) occupants of buildings adjacent to busy roads. At TRRL the various aspects of this problem are being investigated to determine the consequences of surface deterioration and, ultimately, define intervention levels for maintenance purposes.

Effect on Road Users

As a result of extensive studies (11,12) ride assessment by vehicle occupants has been related to surface unevenness. In these studies vehicle vibra-

Figure 7. Measurement of wheel-track rutting with high-speed road monitoring system.

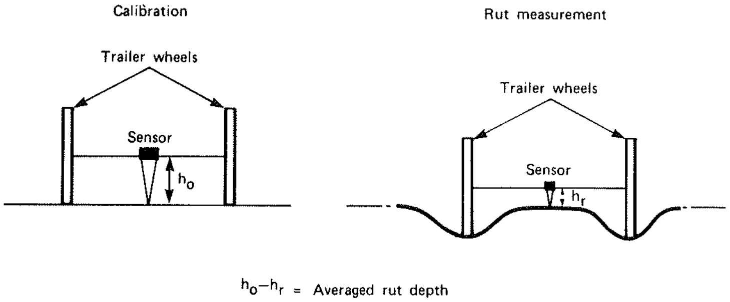


Figure 8. Variation of wheel-track rutting along a motorway and a principal road.

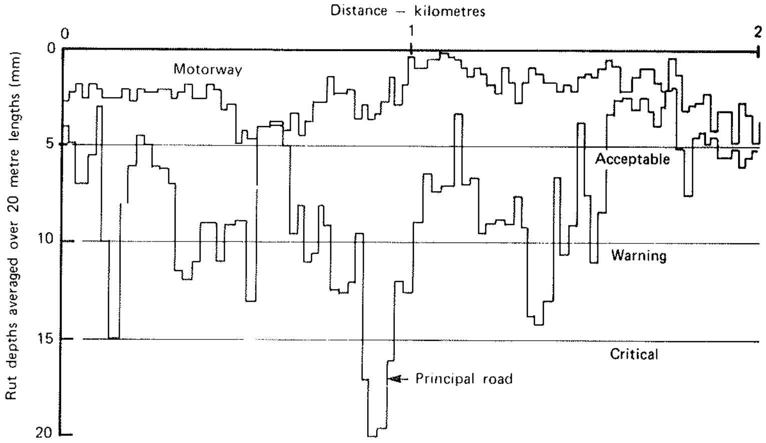
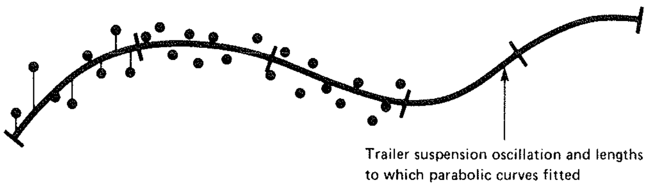


Figure 9. Measurement of macrotexture with laser sensor system.



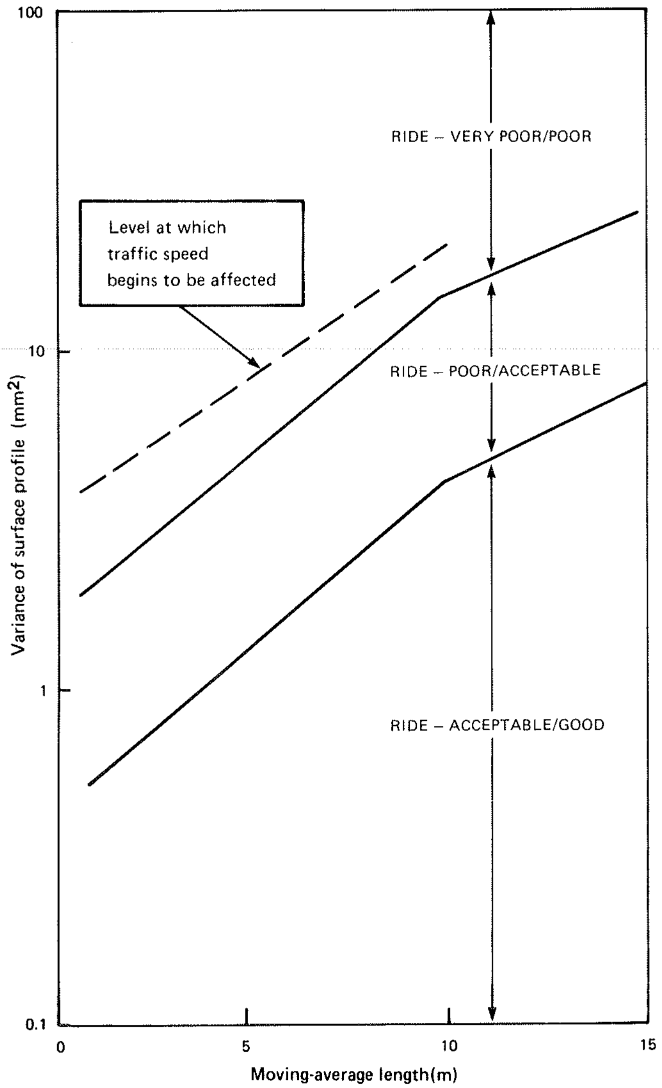
tion, defined by the root mean square (RMS) of vertical acceleration, was correlated with subjective assessments of ride by both a panel of expert assessors and large samples of the motoring public driving their own vehicles over selected sites. The test sites had a range of unevenness and carried traffic operating at speeds greater than 70 km/h. Because of the inherent variability of the subjective assessments, the results of the studies have been interpreted in probabilistic terms. Relations have been computed that give the probability of a ride being rated acceptable or better for given levels of RMS acceleration. For RMS accelerations of less than 0.04 g the analyses show that 90 percent of motorists in automobiles rated the ride as acceptable or better. Motorists driving their own cars were found to be less critical of ride than the panel of expert assessors and truck drivers, and bus passengers were more tolerant of vibration than automobile passengers.

By using profiles of the test sites measured by the road monitoring system, the RMS acceleration values have been correlated with unevenness to give ride criteria for new and in-service roads. Figure 10 shows evenness criteria for roads with traffic speeds greater than 70 km/h; unevenness is defined in Figure 10 in terms of the variance of profile deviations from a moving-average datum. Each variance value reflects the profile unevenness that is associated with profile features less than or equal to the length of the moving average. In the practical application of these criteria, profiles measured by the road monitoring system would be analyzed by using the on-board computer to give the variance values associated with moving-average lengths of 3, 7, 10, and 15 m for comparison with the criteria and thereby define the riding quality of the profile. This analysis is made based on profile lengths selected by the user, typically 300 m in the United Kingdom.

The effect of unevenness on traffic speed has been investigated as part of a general study of the consequences of surface deterioration (13). The level of unevenness at which traffic speed began to be affected on major roads in the United Kingdom is shown in Figure 10. It was concluded that, under existing maintenance practice, deterioration of the surface profile was unlikely to cause a decrease in traffic speed of more than 3 km/h on major roads. Because there are relatively few major roads in the United Kingdom on which unevenness exceeds the level shown in Figure 10, the benefit to road users, in relation to reduced travel times, from improving the profiles on major roads is marginal.

Other consequences that are being investigated include vehicle maintenance and fuel consumption. A pilot survey of vehicle fleet operators indicated that vehicle maintenance was not affected by the levels of unevenness on major roads in the United Kingdom. On other roads there was some indication of an increase in vehicle maintenance that was ascribed to unevenness.

Figure 10. Ride (evenness) criteria for use on major in-service roads.



The effects of unevenness on energy dissipation through tire damping and suspension losses and, hence, fuel consumption are being examined. Initial results show that there is a small but significant increase in energy dissipation for vehicles operating on roads that have levels of unevenness representative of those found on some urban and minor rural roads; the level of energy dissipation depends on vehicle speed and on the spectrum of surface unevenness.

Skidding and Safety

The safety of the road user is a primary consideration of the maintenance engineer in evaluating the condition of in-service roads. Road safety is a complex issue involving the road user, the vehicle, climate, and road conditions. Although it is difficult to quantify the contribution of these elements to road safety, it has been estimated that road-related factors are involved in about a quarter of all road vehicle accidents (14). Skid resistance, particularly in wet conditions, has been shown to have a significant effect on accident risk (14). Aggregate characteristics, surface texture, and, to a lesser extent, rutting are directly related to skid resistance (15), but their effect in any given situation is also greatly affected by road alignment. By using the data provided by the high-speed road monitor together with skid resistance data, the effect of road alignment and road surface parameters (both individually and in combination) on accident risk can be examined by means of correlation methods. Once the parameter levels associated with a significant accident risk were determined from studies, the equipment would be used to survey road alignment and surface condition to locate those sections of the network that have a significant accident risk. With a knowledge of traffic densities and speeds, the cost in human and material resources of road-related safety measures can be better estimated.

Structural Deterioration

The traditional method of detecting structural deterioration on roads in the United Kingdom is visual inspection. The development of the deflectograph (16) and of criteria for interpreting its measurements (17) has resulted in widespread use of this instrument as a means of providing an objective evaluation of structural conditions in quantitative terms. A disadvantage of both visual inspection and the deflectograph for survey work is their relative slowness.

The high-speed road monitor has been used to carry out a continuing survey of longitudinal profile on a sample of different road constructions over a period of 4 years. Analysis of the data from this survey shows that the rate of change of unevenness correlates better with the structural condition of pavements than does the absolute level of unevenness; the rate of change of unevenness, defined as the proportional change in profile variance over 10 percent of the nominal life of the test site, was computed for each 25-m length of each test site. The profile variance was computed in relation to a datum derived from a 3-m moving average of the profile.

Work is continuing on the development of criteria for the early detection of structural distress on major roads. In practice, those sections where structural distress was indicated would then be surveyed in detail by using the deflectograph and visual inspection to ascertain the nature and extent of the distress and determine the necessary strengthening treatments (17).

PAVEMENT MAINTENANCE OPTIMIZATION

With about £10,000/km being spent each year on maintenance of the U.K. trunk road system and more than £1,000 on other roads [£1 = U.S. $2.32 (1980)] there is clearly scope for investing money in techniques and equipment that help to reduce the total annual maintenance bill and allocate the available funds in the most cost-effective manner.

In response to economic pressures maintenance management has developed slowly over the years. As new equipment and techniques have become available they have been put to effective use, but without producing a complete solution to the overall problem of allocating resources. The techniques used include engineering judgment; visual inspection in surveys such as CHART, which cost between £30/km (rural) and £250/km (urban); SCRIM, which costs £10/km; and the deflectograph, which costs £90/km. With the advent of the high-speed road monitor, which can survey the network at up to 200 km/day at a cost of about £5/lane-km, and parallel improvement of the bump integrator (18), two powerful survey tools have been made available that can take the subjective judgment out of the first stage of inspecting the network.

For the development of a satisfactory economic model of maintenance management, the various measures of pavement condition should be linked to costs of remedial treatment, vehicle operating cost, and non-road-user costs. The results of road condition surveys might then be used to adjust maintenance interventions to minimize the total discounted cost to the community.

In a road investment model developed by the Overseas Unit of TRRL for use in countries with unpaved roads, an economic optimum is more closely approached by taking into account the effect of highway maintenance standards on vehicle operating costs (19). Vehicle operating costs are, of course, much less affected by the relatively lower levels of deterioration of the generally better-quality paved surfaces in developed countries. However, the accuracy of measurement and the processing capability of the high-speed road monitor allied with studies on the effects of unevenness such as those described previously now provide a means of examining this difficult problem.

CONCLUSIONS

Described in this paper is the operation of a high-speed road monitoring system developed at TRRL that measures longitudinal profile, rut depth, and surface texture. Work is underway to include cross-fall, gradient, and horizontal curvature. As further enhancements are required they can be added to the system to make it even more effective for rapidly surveying the condition of the road network.

Longitudinal profile and rut measurements provide an assessment of ride quality and indicate structural condition. Although the high-speed road monitor does not measure skid resistance directly, its measurements of road alignment, profile, surface texture, and rutting can be used to locate potentially hazardous sections of the road network.

The contribution the high-speed road monitor can make to a maintenance management system has been briefly discussed, particularly its ability to provide up-to-date information on the condition of the network and to direct more specialized equipment to those distressed areas where its use would be most cost effective.

ACKNOWLEDGMENT

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REFERENCES

1. U.K. Ministry of Transport. Report of the Committee on Highway Maintenance. Her Majesty's Stationary Office, London, 1970.
2. P.J.F. Wingate and C.H. Peters. The CHART System of Assessing Structural Maintenance Needs of Highways. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. SR 153 UC, 1973.
3. P.G. Jordan. Measurement of Road Surface Shape Using a Laser Sensor. *In* Sensors in Highway and Civil Engineering, Institution of Civil Engineers, London, 1981.
4. P.B. Still and M.A. Winnett. Development of Contactless Displacement Transducer. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 690, 1975.
5. P.B. Still and P.G. Jordan. Evaluation of the TRRL High-Speed Profilometer. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 922, 1980.
6. H. Braun and F.-J. Laermann. Comparative Measurements of Unevenness Between the TRRL High-Speed Profilometer and the Braunschweig-Profilograf. Strasse und Autobahn, No. 12, 1980.
7. P.G. Jordan and P.B. Still. Measurement of Rut Depths in Road Surfaces by the TRRL High-Speed Profilometer. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 1037, 1982.
8. D.R.C. Cooper. Measurement of Road Surface Texture by a Contactless Sensor. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 639, 1974.
9. J.R. Hosking and P.B. Still. Measurement of the Macrotexture of Roads: Part 1--Trials with the Contactless Sensor on Motorway M1. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. SR 498, 1979.
10. P.B. Still. Measurement of Groove Dimensions on Concrete Pavements by a Contactless Sensor. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. SR 443, 1978.
11. D.R.C. Cooper and J.C. Young. Road Surface Irregularity and Vehicle Ride. *In* Human Factors in Transport Research, Academic Press, London, Vol. 2, 1980, pp. 105-113.
12. J.C. Young and P.G. Jordan. Road Surfacings and Noise Inside Saloon Cars. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. SR 655, 1981.
13. D.R.C. Cooper, P.G. Jordan, and J.C. Young. The Effect on Traffic Speeds of Resurfacing a Road. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. SR 571, 1980.
14. B.E. Sabey. Accidents: Their Cost and Relation to Surface Characteristics. Presented at Symposium on Safety and the Concrete Road Surface: Design, Specification, and Construction, Birmingham, England, 1973.
15. G.F. Salt. Research on Skid Resistance at the Transport and Road Research Laboratory (1927-1977). Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. SR 340, 1977.
16. C.K. Kennedy, P. Fevre, and C.S. Clarke. Pavement Deflection: Equipment for Measurement in the United Kingdom. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 834, 1978.
17. C.K. Kennedy and N.W. Lister. Prediction of Pavement Performance and the Design of Overlays. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 833, 1978.

18. P.G. Jordan and J.C. Young. Developments in the Calibration and Use of the Bump Integrater. Journal of the Institute of Highway Engineers, No. 4, April 1981.
19. R. Robinson, et al. A Road Transport Investment Model for Developing Countries. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 674, 1975.

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Use of Response-Type Roughness Meters for Pavement Smoothness Acceptance in Georgia

WOUTER GULDEN, JERRY STONE, AND DENNIS RICHARDSON

The use of response-type, road-roughness-measuring systems as part of surface tolerance specifications is attracting increasing interest among highway agencies as a rapid, inexpensive means of measuring the smoothness of roads during and after construction. Problems such as calibration, vehicle maintenance, and the repeatability of test results must be taken into account and resolved or minimized when these roughness-measuring systems are used for acceptance or rejection of projects for smoothness. The Georgia Department of Transportation has been using road meters in its specifications since 1972 for acceptance of projects and since 1979 for both rejection and acceptance. The evolution of the road-roughness-measuring program in Georgia, the calibration and operating procedures, the current smoothness specifications, and the use of Mays meter data during construction are described.

The surface smoothness testing program of the Georgia Department of Transportation (DOT) has evolved over the years from the rolling straightedge to trailer-mounted Mays ride meters and from testing for information purposes only to project construction control and acceptance. Many changes in equipment and procedures were made during this evolution to enhance the program and to ensure acceptance of the test results by contractors and project engineers alike.

Before 1966 the rolling straightedge was used to measure and control pavement roughness. Realizing the shortcomings of the straightedge in relating surface profile deviations to ridability, the Georgia DOT began to experiment with the CHLOE profilometer, but it soon became obvious that this device was too slow to be used in a large-scale program.

In 1968 Georgia began using the Portland Cement Association (PCA) road meter on a limited basis to check the roughness of various Interstate projects and some other selected paving projects. The road meter was installed in a carry-all type of vehicle, although it was designed to be installed in a standard-sized car.

The road-meter program was expanded in 1972 with the purchase of a PCA meter for each of the seven highway districts in Georgia so that each paving project could be monitored during construction. Each project was also measured for ridability before construction so that it would be possible to determine the amount of improvement in ridability after resurfacing.

The test results had previously been provided to contractors and project engineers so that they could become familiar with roughness testing and the results that were being obtained. In 1972 the Georgia DOT began using the PCA meter in lieu of the straightedge for acceptance of pavement smoothness on construction projects. If a project met the PCA meter specification it was accepted without further testing, but if it failed to meet these ridability requirements the failing sections were then retested with the rolling straightedge. The PCA meter was therefore used only as an acceptance tool, and any penalties were assessed based on rolling-straightedge results.

The carry-all vehicles were replaced during the next few years, and each district purchased replacement vehicles independently. By 1976 the meters were mounted in a variety of vehicle types, such as suburbans, station wagons, and cars of various sizes and makes. During this time the PCA meter was still used for acceptance testing only, and variations in road profile response from the various vehicles were unimportant to the contractor because penalties were still being assessed based on straightedge results.

Monitoring of the results obtained with the PCA meter and the rolling straightedge showed no consistent correlation between these two devices. Frequently, a section that failed the PCA meter requirements would be assessed no penalties based on the rolling-straightedge method. Sections determined to be acceptable by the road meter were sometimes found to have failed the straightedge requirements. It was obvious that the two devices did not give compatible results on all types of roads and roughness levels.

In 1975 the decision was made to standardize the PCA meter so that it could eventually be used for construction control and entirely replace the rolling straightedge. A testing program was conducted to compare PCA meter results obtained by various vehicles. The station wagon was chosen as a standard test vehicle and a fleet of station wagons was purchased.

Several other changes were made at the same time in an effort to standardize the equipment and upgrade the reliability of the testing program. An automatic null system was added to all PCA meters, radial tires were used on all test vehicles, and